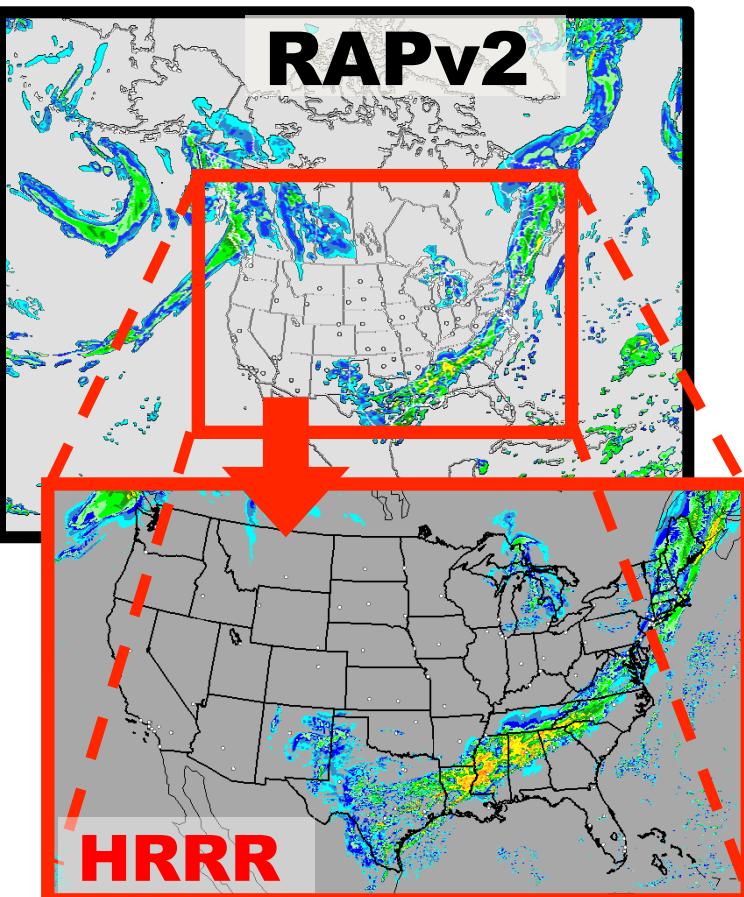




# NCEP WCOSS Science Quarterly



**Rapid Refresh  
Version 2  
(and HRRR)**

**Stan Benjamin, Steve Weygandt,  
Curtis Alexander, Ming Hu – NOAA  
Earth System Research Laboratory**

**Geoff Manikin, Geoff DiMego –  
NCEP/EMC**



# Hourly Updated NOAA Models



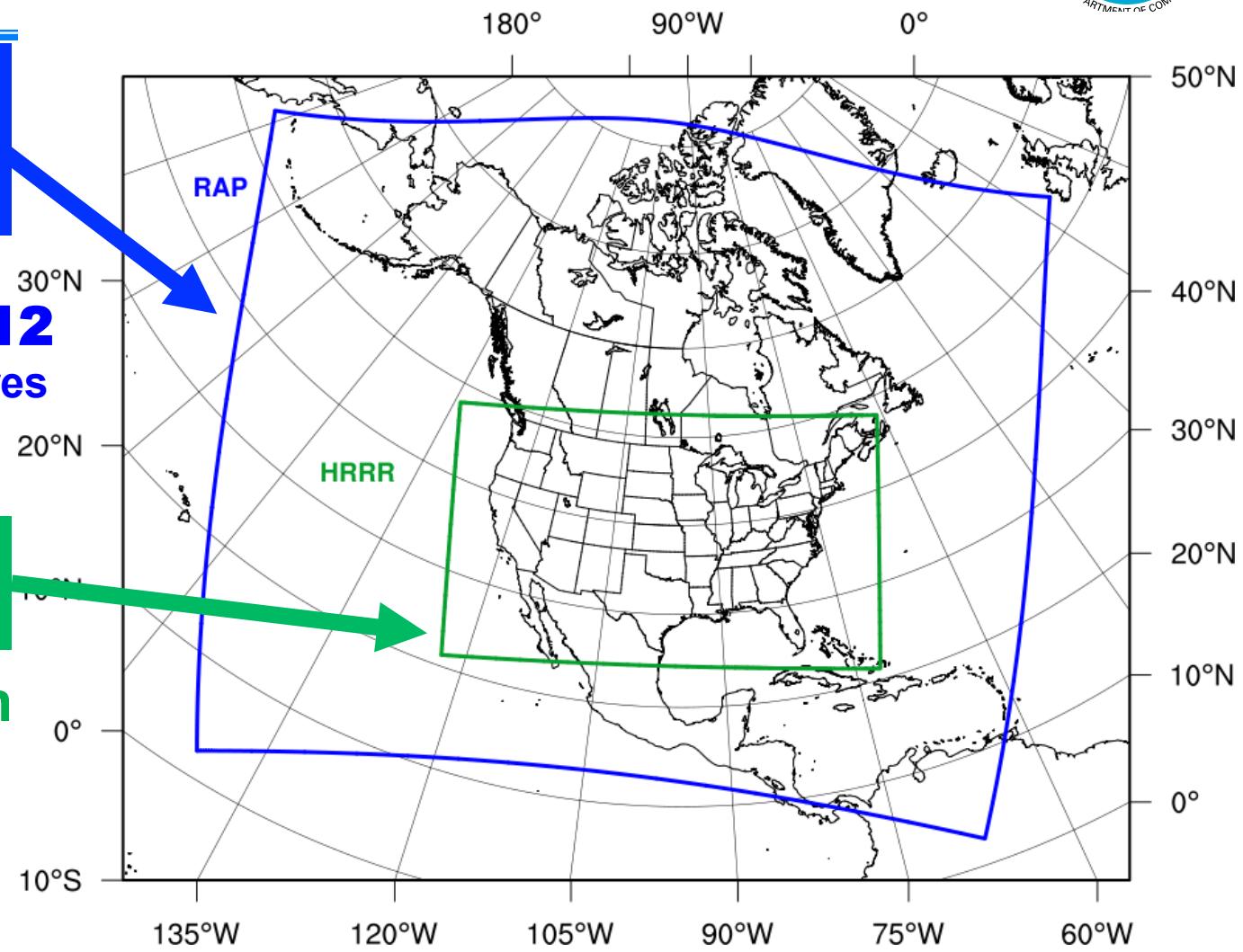
13km Rapid Refresh (RAP) (mesoscale)

**Replaced RUC at NCEP 05/01/12**  
WRF, GSI, RUC features  
**RAPv2 – Q1 FY14**

3km HRRR (storm-scale)

High-Resolution Rapid Refresh  
Experimental 3km nest inside RAP,  
hourly 15-h fcst

**HRRR-NCEP – Q2 FY14**





# RAPv2-HRRR Outline

What has happened since RAPv1 freeze – Dec 2010

- *Changes made to experimental RAP controlled through svn, once yearly (frozen on jet/zeus otherwise)*
- Jan-Mar 2012 changes to RAPv2/HRRR (@ESRL)
  - Highlights: near-surface / radar data assimilation, cloud assimilation
- Jan-April 2013 changes (first on jet/zeus)
  - All now in testing on WCOSS – RAPv2 and HRRR (r763)
  - Highlights:
    - Ensemble/hybrid DA (RAPv2), 3km/ radar assimilation
    - Model changes – boundary layer, land-surface
  - Examples of new improvements



# RAPv2/HRRR Users and Applications



U.S. DEPARTMENT OF COMMERCE

Aviation Weather Center (AWC): 2-D grids

Federal Aviation Administration (FAA) Command Center

National Center for Atmospheric Research (NCAR): 2-D, 3-D, 15-min grids

Operational evaluation in CoSPA

Storm Prediction Center (SPC): 2-D grids

Operational severe weather forecasting and evaluation

National Severe Storms Laboratory (NSSL): 2-D, 3-D and 15-min grids

Mesoscale analysis, Short-term precipitation forecasts

National Centers for Environmental Prediction (NCEP): 15-min grids

Real Time Mesoscale Analysis (RTMA) (advanced 15-min HRRR-based RTMA)

Energy companies and energy forecast consulting companies

Department of Energy/NOAA Wind Forecast Improvement Project (WFIP), solar (SunShot)

~12 energy private sector companies (WindLogics, 3Tier, AWS Truepower, Iberdrola, Weather Channel, etc.)

Real-time forecasts of turbine-level wind and solar irradiance

Colorado State University (CSU/CIRA): 2-D grids

Verification of solar irradiance forecasts at SURFRAD sites

National Weather Service (NWS), Regions, FOs, WPC: 2-D and 3-D grids

Operational weather forecasting

United States Air Force (USAF): 2-D grids

Operational weather forecasting

Aviation

Severe Weather

Energy (Load and Renewable Generation)

Forecasting



# RAPv2 Model Overview

- Upgrade scheduled for December 2013
- Rapid Refresh description
  - Used by SPC, AWC, WPC, FAA, NWS FOs, energy industry, and others for short-range forecasts and hourly analyses
  - 13 km horizontal resolution, 50 level
  - Output grids: 13, 20, and 40 km CONUS, 32 km full domain, 11 km Alaska, 16 km Puerto Rico
  - 24 cycles/day – each run out to 18 hours
  - 6-hour catch-up “partial” cycle run twice per day w/ GFS
- Dependencies downstream
  - Downscaled RAP serves as first guess for RTMA
  - RAP serves as initial condition for 7 SREF members
  - RAP will be used to initialize Hi-Res Rapid Refresh (HRRR), scheduled for implementation in early 2014



# RAPv2 Transition to NCEP

Data Assimilation	Assimilation Type	PBL Pseudo Innovations	Soil Adjustment	Low-Cloud Building	Snow Cover Building	Lightning Obs (radar refl proxy)	Tower/Nacelle/Sodar Obs
RAPv1	GSI 3D-VAR	No	No	No	No	No	No
RAPv2	GSI EnKF-3DVAR Hybrid	Yes	Yes	Yes	Yes + rev trimming	Yes	Yes

Model	Version	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	SW Radiation Update	Land Use	LSM	PBL	Microphysics	Radiation LW/SW
RAPv1	WRF-ARW V3.2	5 <sup>th</sup> /3 <sup>rd</sup>	Monotonic	w-Rayleigh 0.02	30 min	USGS	RUC 6-lev	MYJ	Thompson V3.2	RRTM/Goddard
RAPv2	WRF-ARW v3.4.1+	5 <sup>th</sup> /5 <sup>th</sup>	Positive-Definite	w-Rayleigh 0.2	10 min	MODIS Fractional	RUC 9-lev	MYNN	Thompson v3.4.1	RRTM/Goddard

## **Cloud and Precipitating Hydrometeor Analysis Improvements in RAPv2**

Surface temperature-dependent radar-hydrometeor building

Consistent rain (droplet) number concentration and mixing ratio retrievals from radar refl obs

Rain and snow mixing ratio retrievals reversible with Thompson reflectivity diagnostic

Conservation of virtual potential temperature during cloud building/clearing

Water vapor reduced to subsaturation when cloud clearing

Elevation correction to match model and observed precipitable water

Limitation of precipitable water innovation to 10% of background



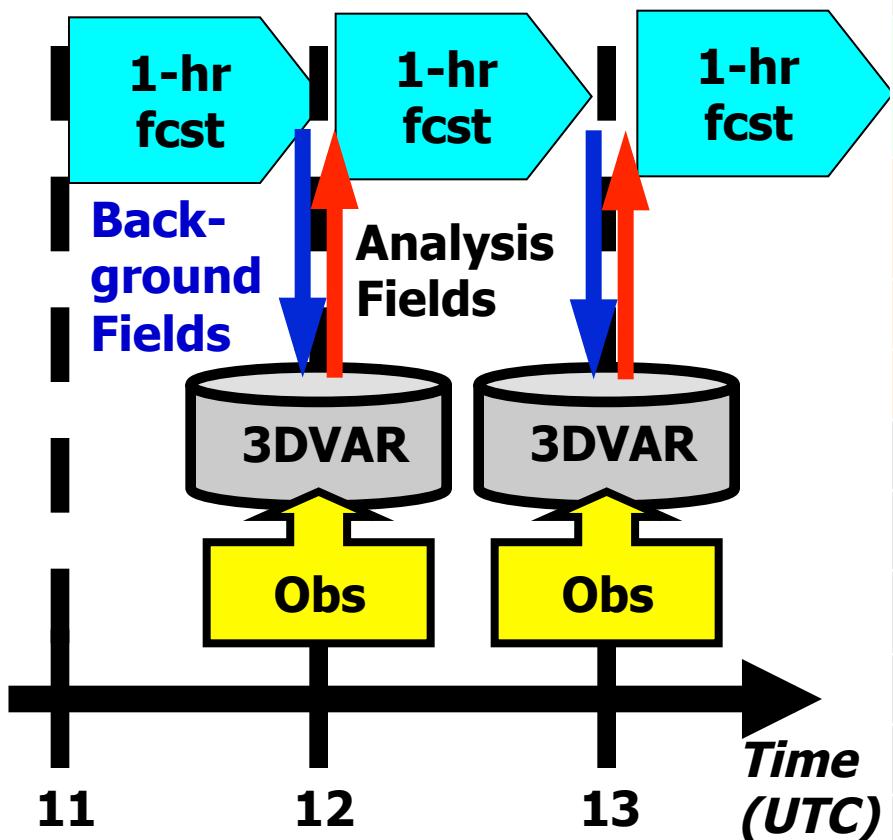
# Rapid Refresh

## Hourly Update Cycle

**Partial cycle atmospheric fields – introduce GFS information 2x/day**

**Cycle hydrometeors**

**Fully cycle all land-sfc fields  
(soil temp, moisture, snow)**

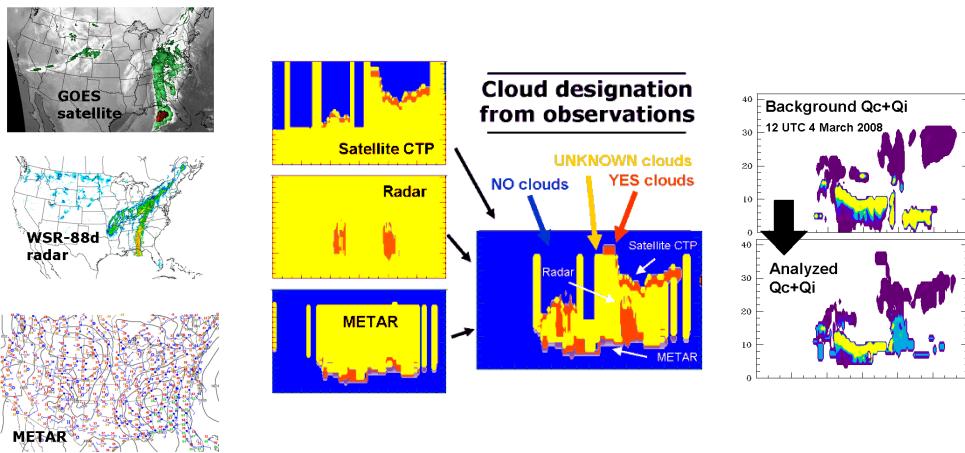


Hourly Observations	RAP 2013 N. Amer
Rawinsonde (T,V,RH)	120
Profiler – NOAA Network (V)	21
Profiler – 915 MHz (V, Tv)	25
Radar – VAD (V)	125
Radar reflectivity - CONUS	1km
Lightning (proxy reflectivity)	NLDN, GLD360
Aircraft (V,T)	2-15K
Aircraft - WVSS (RH)	0-800
Surface/METAR (T,Td,V,ps,cloud, vis, wx)	2200- 2500
Buoys/ships (V, ps)	200-400
Mesonet (T, Td, V, ps)	flagged
GOES AMVs (V)	2000- 4000
AMSU/HIRS/MHS radiances	Used
GOES cloud-top press/temp	13km
GPS – Precipitable water	260
WindSat scatterometer	2-10K
Nacelle/Tower/Sodar	20/100/10

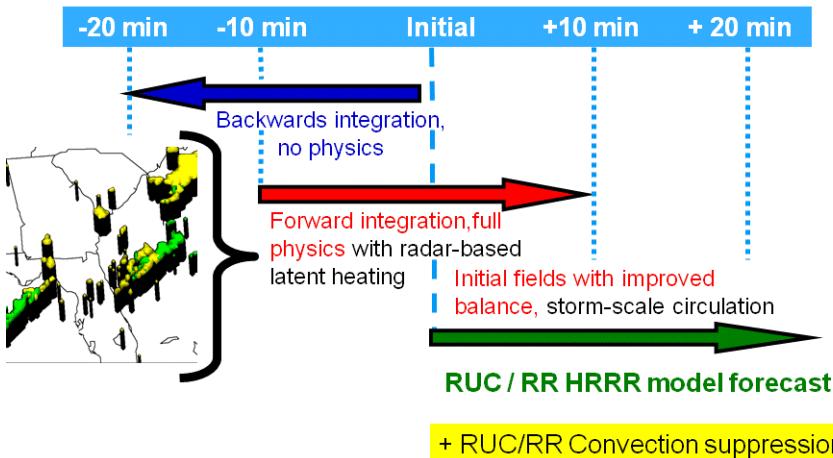


# Rapid Refresh Specific Analysis Features

## Cloud and hydrometeor analysis



## Digital filter-based reflectivity assimilation (DDFI)



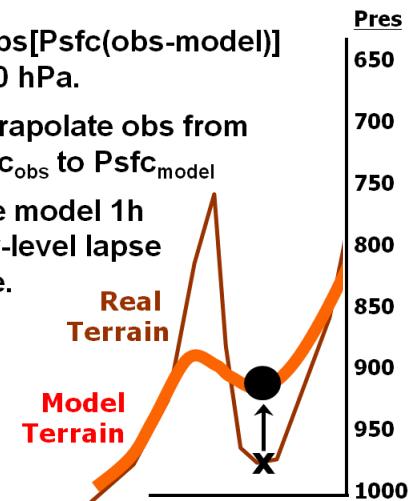
## Special treatments for surface observations

### Elevation correction

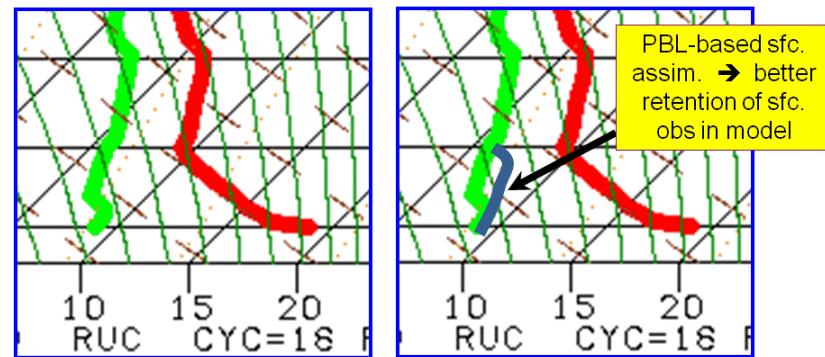
If  $\text{abs}[\text{Psfc}(\text{obs-model})] < 70 \text{ hPa}$ .

Extrapolate obs from  $\text{Psfc}_{\text{obs}}$  to  $\text{Psfc}_{\text{model}}$

Use model 1h low-level lapse rate.

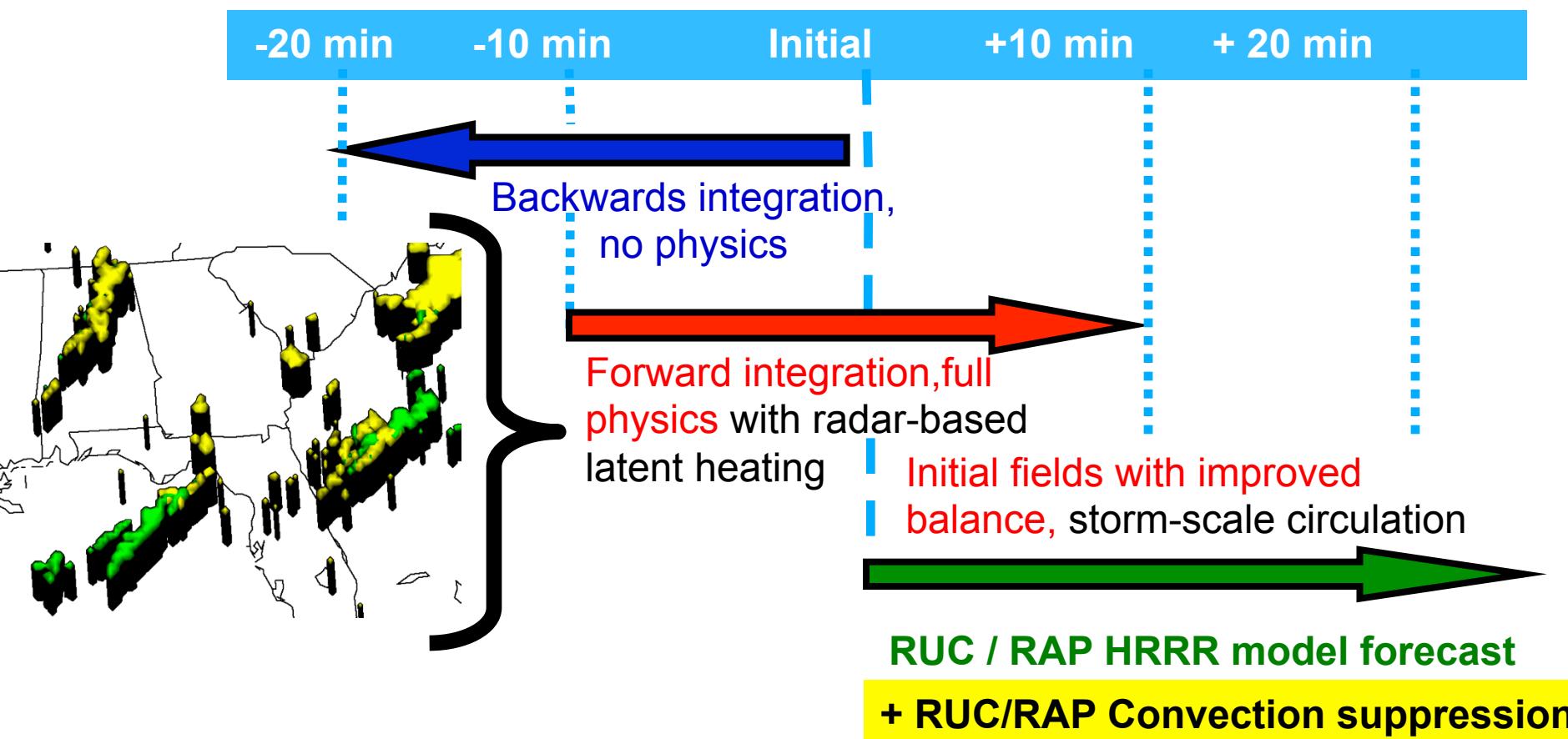


### PBL-based pseudo-observations



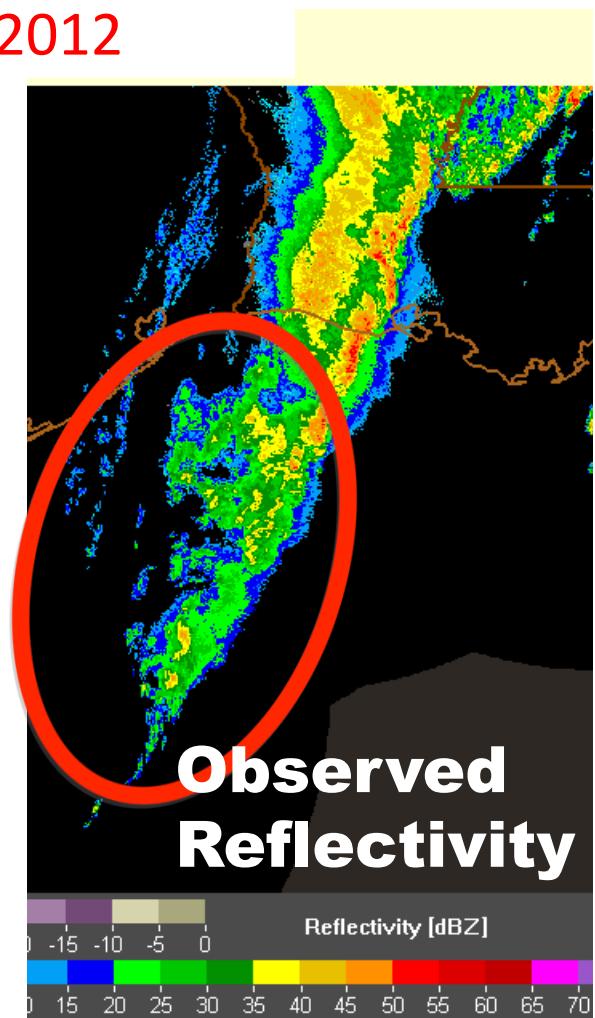
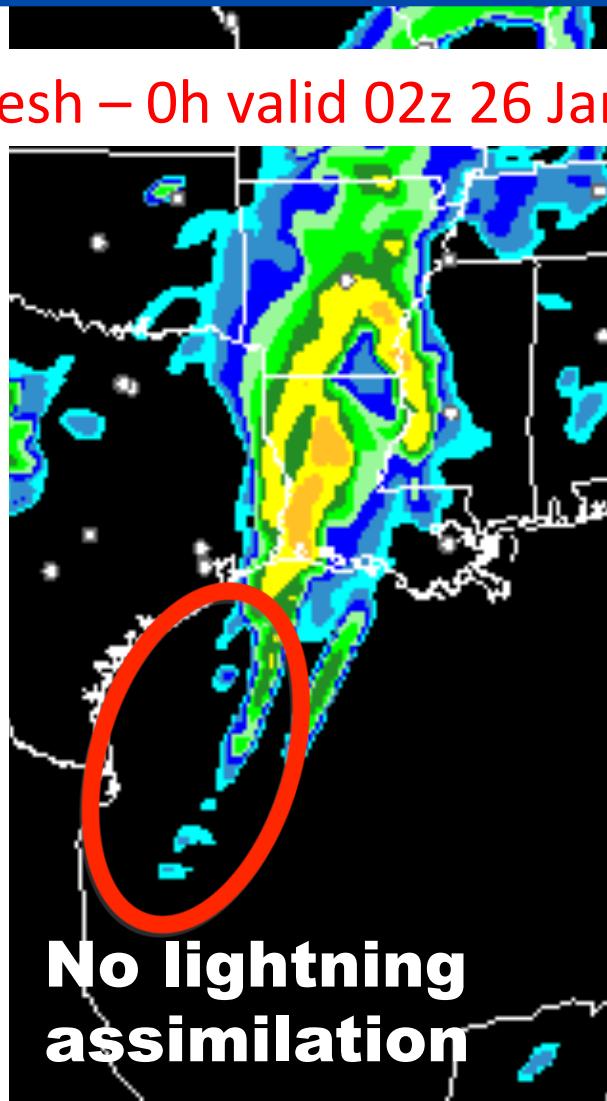
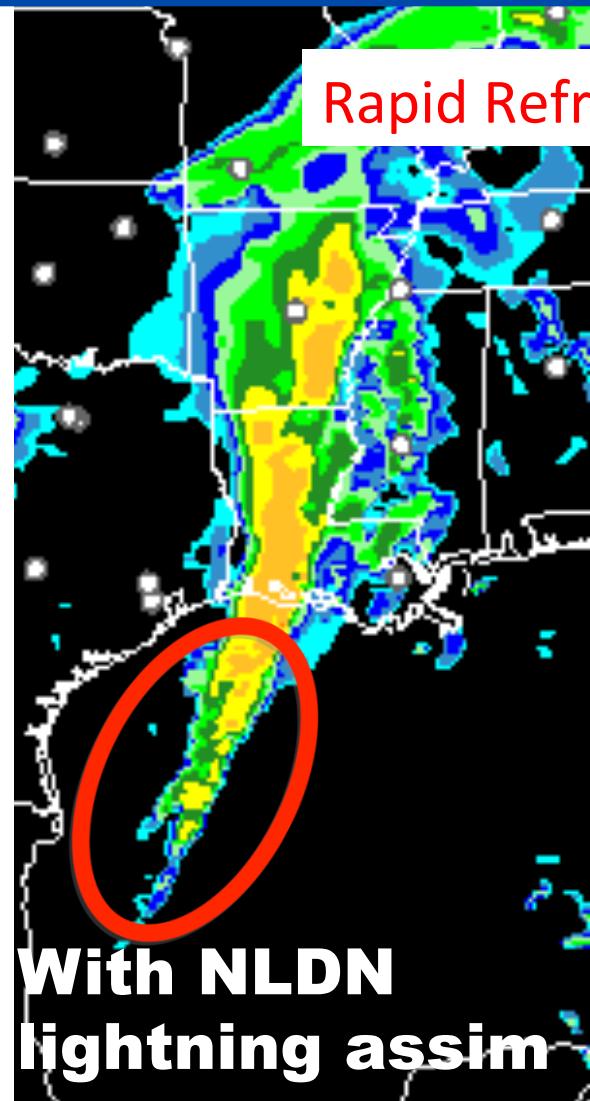
# RAP Radar Reflectivity Assimilation

Digital filter-based reflectivity assimilation initializes ongoing precipitation regions





# RAPv2 Lightning Assimilation



**Improved convective coverage off the coast with lightning assimilation**



# RAPv2 2013 Data Assimilation

U.S. DEPARTMENT OF COMMERCE  
NOAA

**13 km  
RAP  
Cycle**

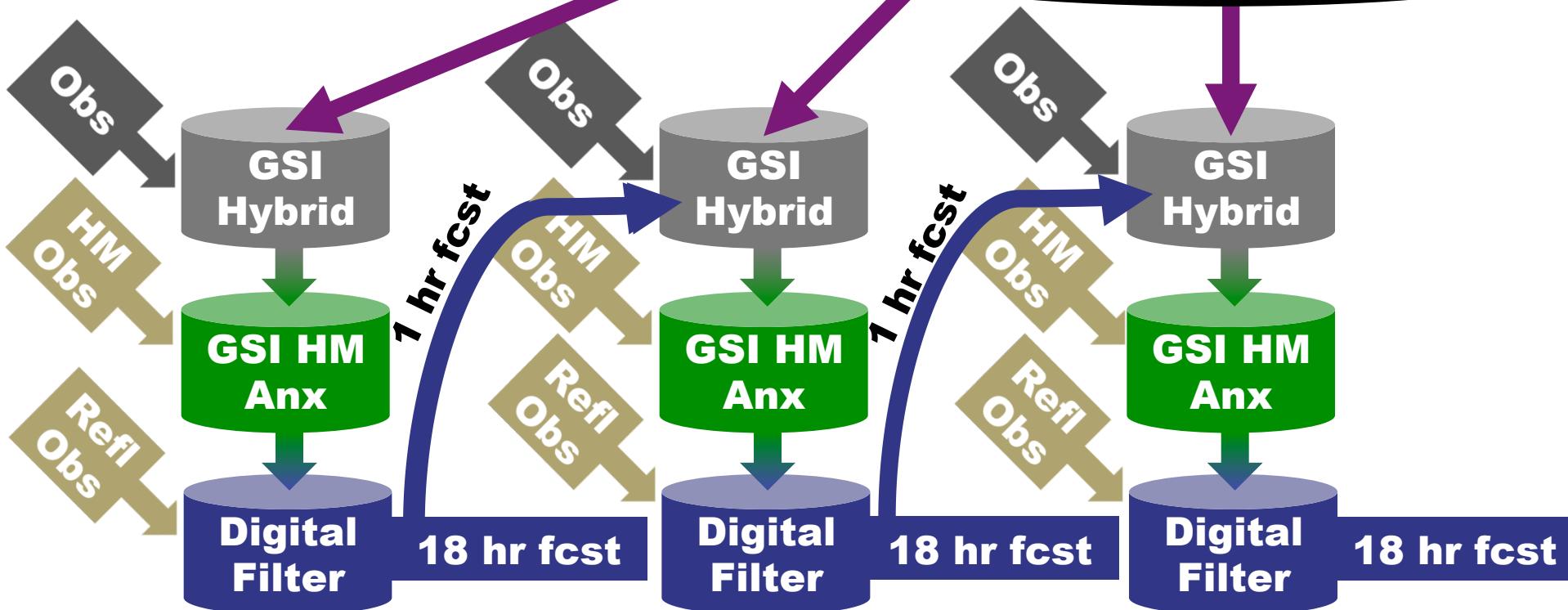
**13z**

**14z**

**15z**

**ESRL/GSD RAP 2013**  
**Uses GFS 80-member ensemble**  
**Available four times per day**  
**valid at 03z, 09z, 15z, 21z**

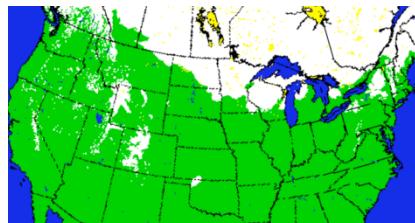
**80-member GFS EnKF**  
**Ensemble forecast valid at**  
**15Z (9-hr fcst from 6Z)**



# RAPv2 2013 Snow Updating

## Surface Snow Water Equivalent Valid 00z 05 April 2013

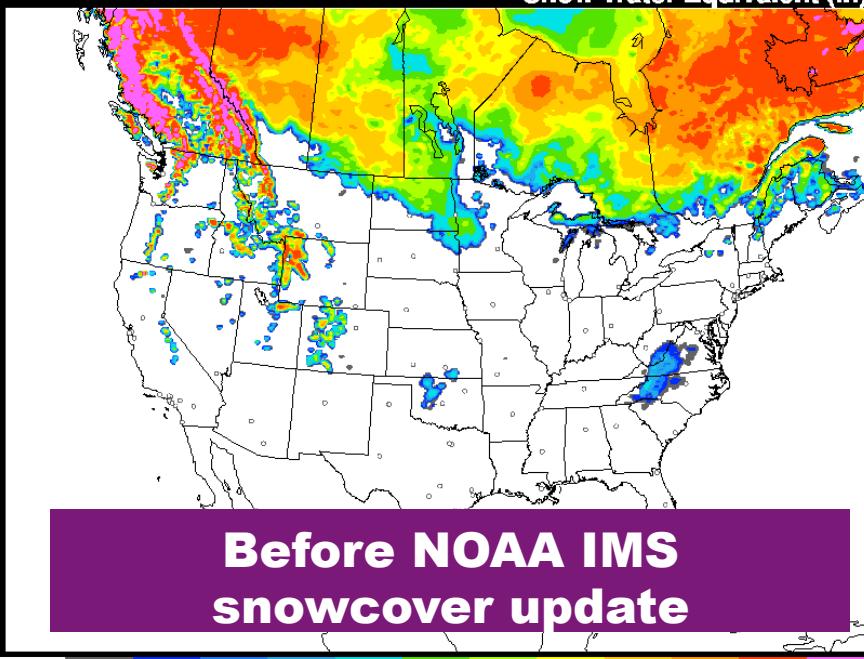
**GSI Snow  
Cover Analysis  
(Run 00z Daily)**



**Using Interactive Multisensor  
Snow/Ice Mapping System  
(IMS)**

RAP-primary-ESRL 04/04/2013 (23:00) 1 hr fcst

Valid 04/05/2013 00:00 UTC  
Snow Water Equivalent (in)

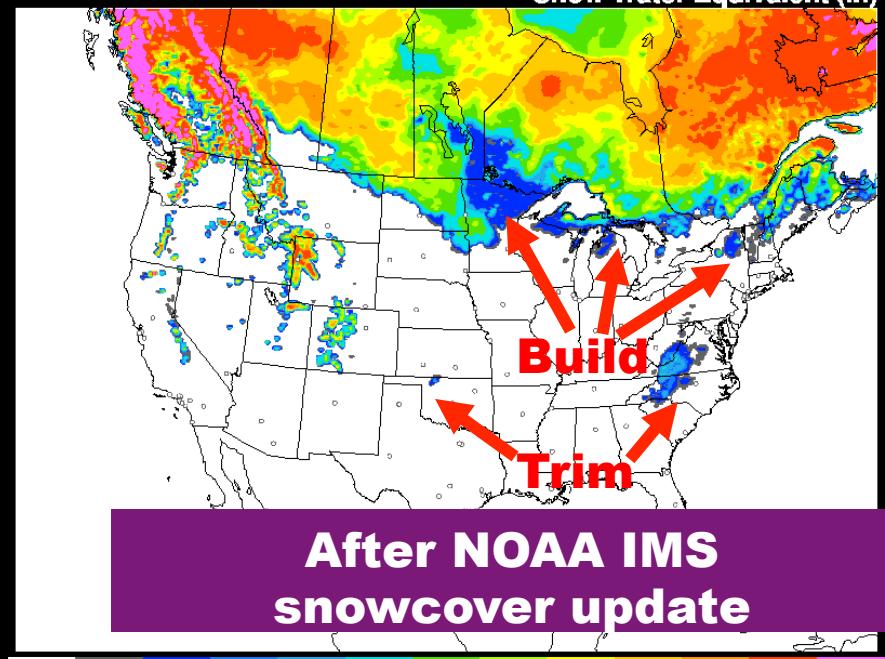


**Before NOAA IMS  
snowcover update**

.01 .1 .3 .5 1 2 3 4 5 7.5 10 20

RAP-primary-ESRL 04/05/2013 (00:00) 0 hr fcst

Valid 04/05/2013 00:00 UTC  
Snow Water Equivalent (in)



**After NOAA IMS  
snowcover update**

.01 .1 .3 .5 1 2 3 4 5 7.5 10 20

**Improved snowcover**

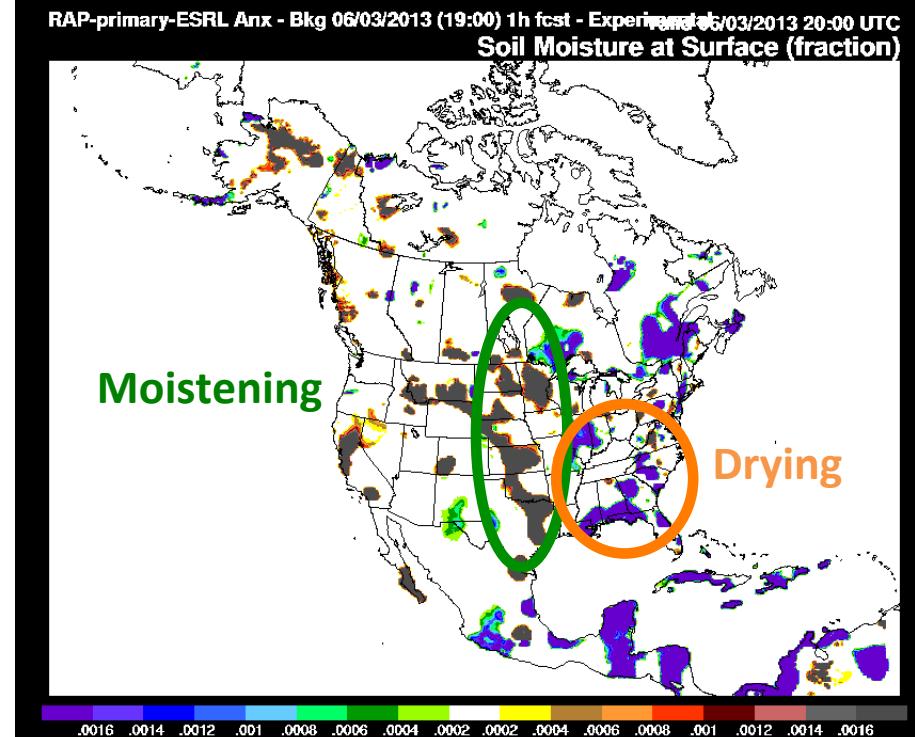
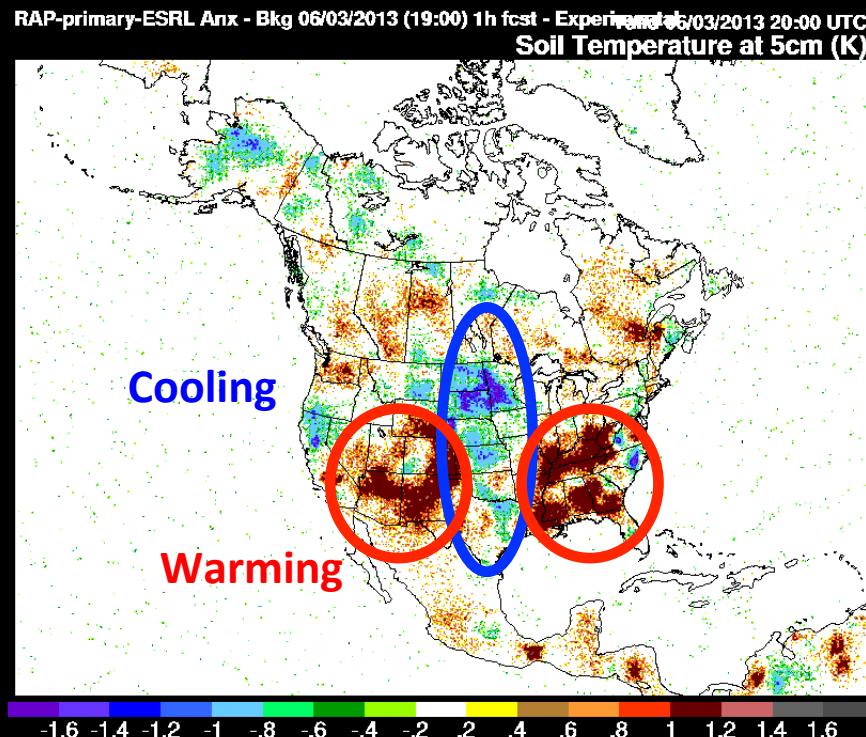


# RAPv2 Soil Adjustment

**Soil Temperature**

**Valid  
20 UTC  
03 June 2013**

**Soil Moisture**



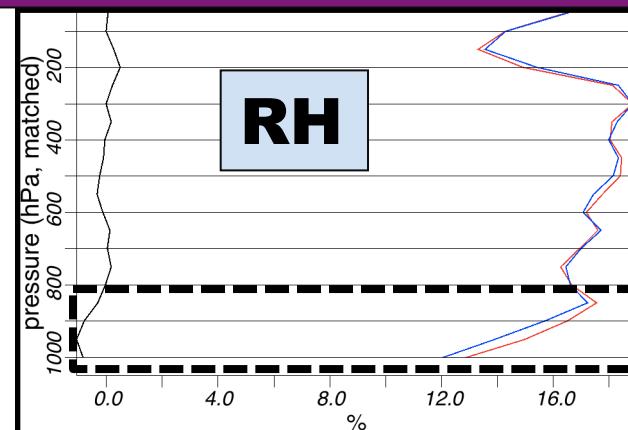
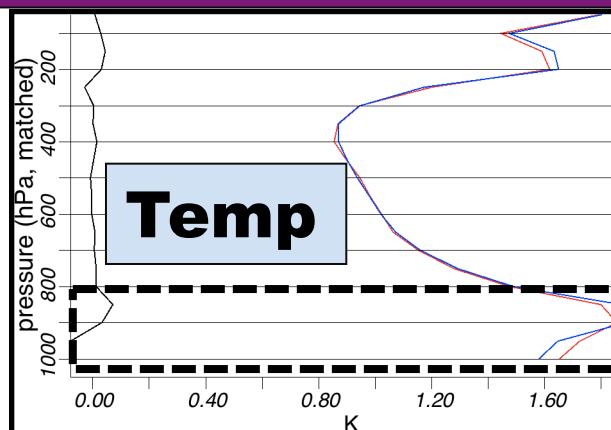
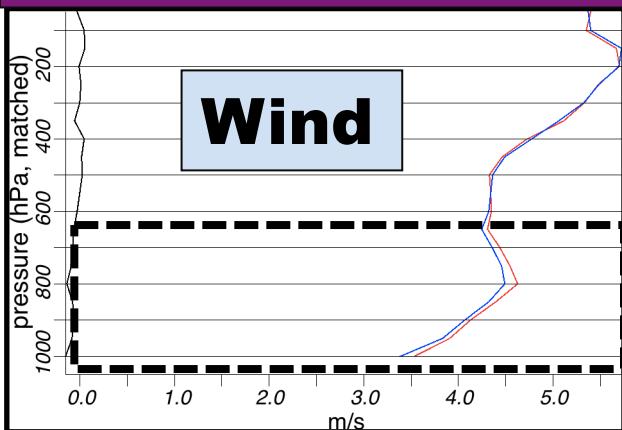
**Based upon surface temperature and dewpoint analysis increments  
– new option within GSI. Critical also for HRRR**

# RAP/HRRR 2013 – PBL/LSM changes

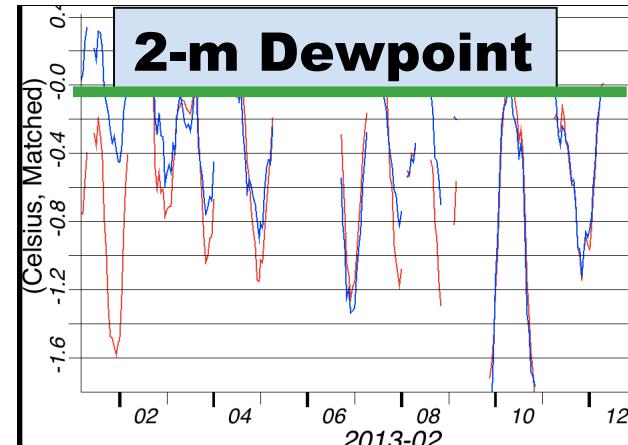
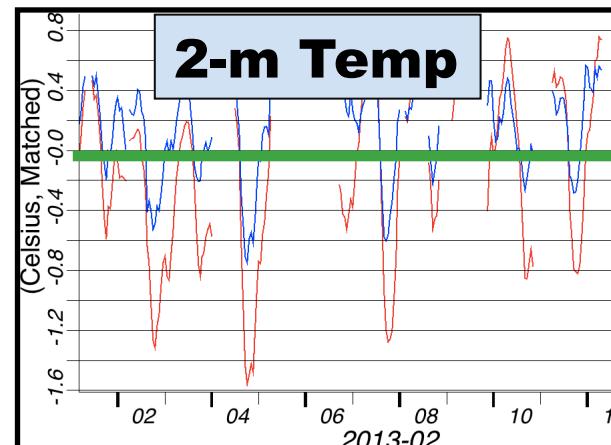
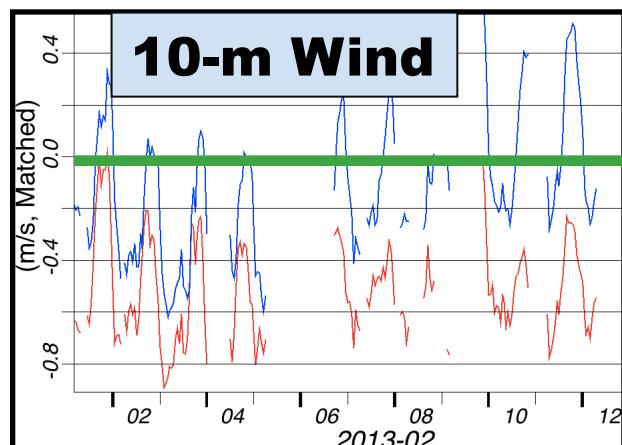
RMSE Vertical Profiles: Soundings 14 Jan – 11 Feb 2013

— MYNN, 9-level RUC LSM — MYJ, 6-level RUC LSM

06-hr Forecast



BIAS (Observed – Forecast) 01 Feb – 11 Feb 2013



Improved near-surface environment



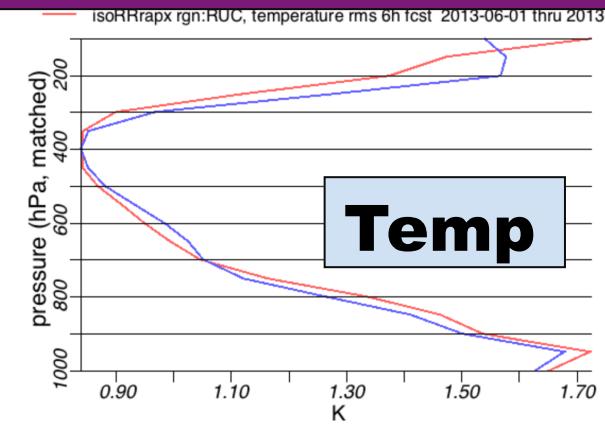
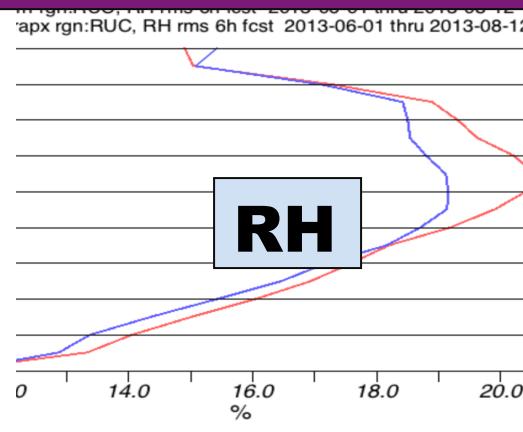
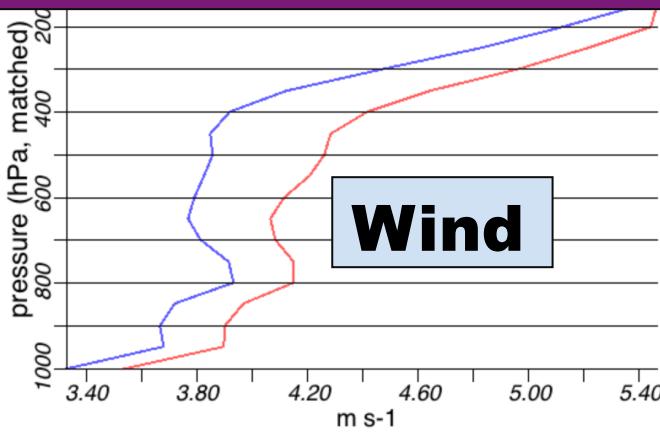
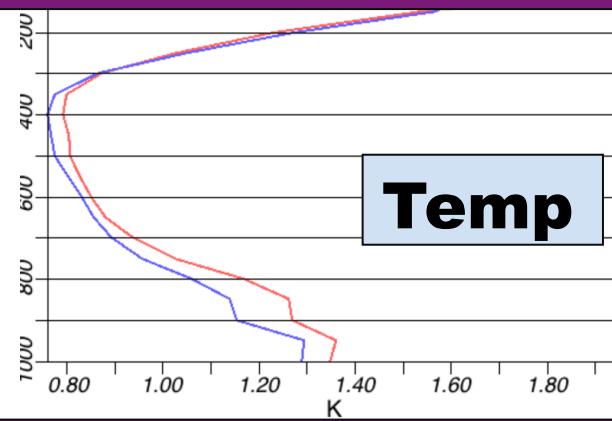
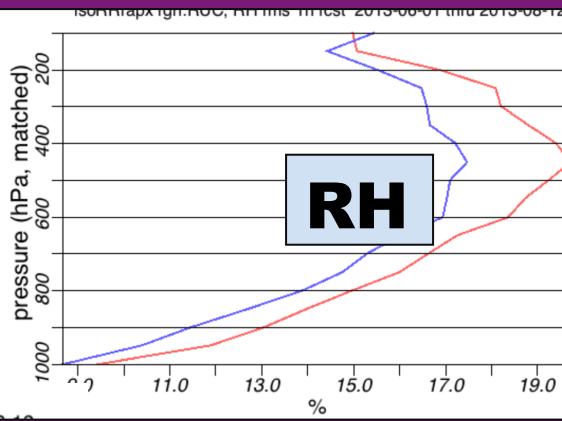
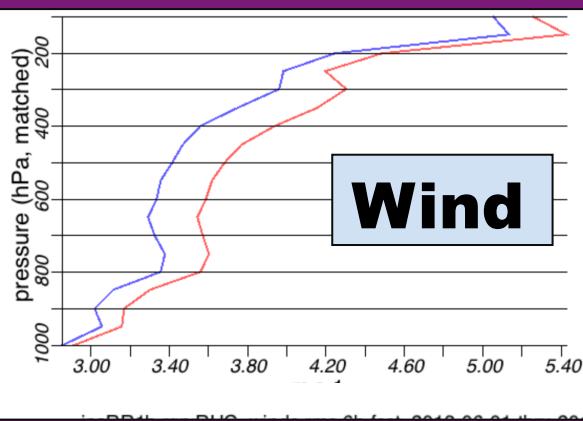
# RAPv2 vs. RAPv1 – upper-air

RMSE Vertical Profiles: Soundings from 1000-100 mb

1 June – 12 August 2013

RAPv2

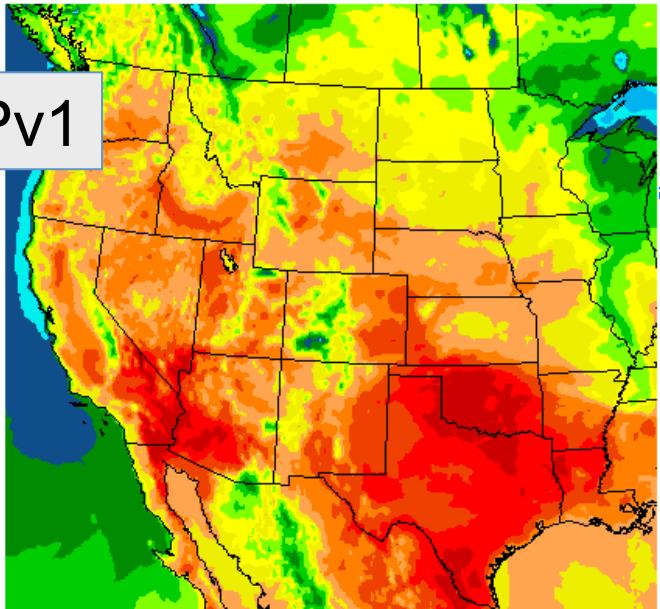
RAPv1 (NCEP OPER)



Improved upper-air environment

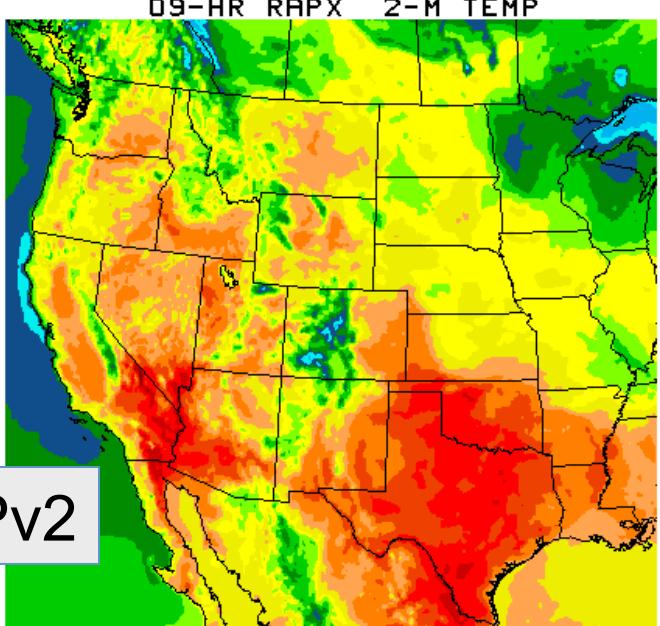


RAPv1



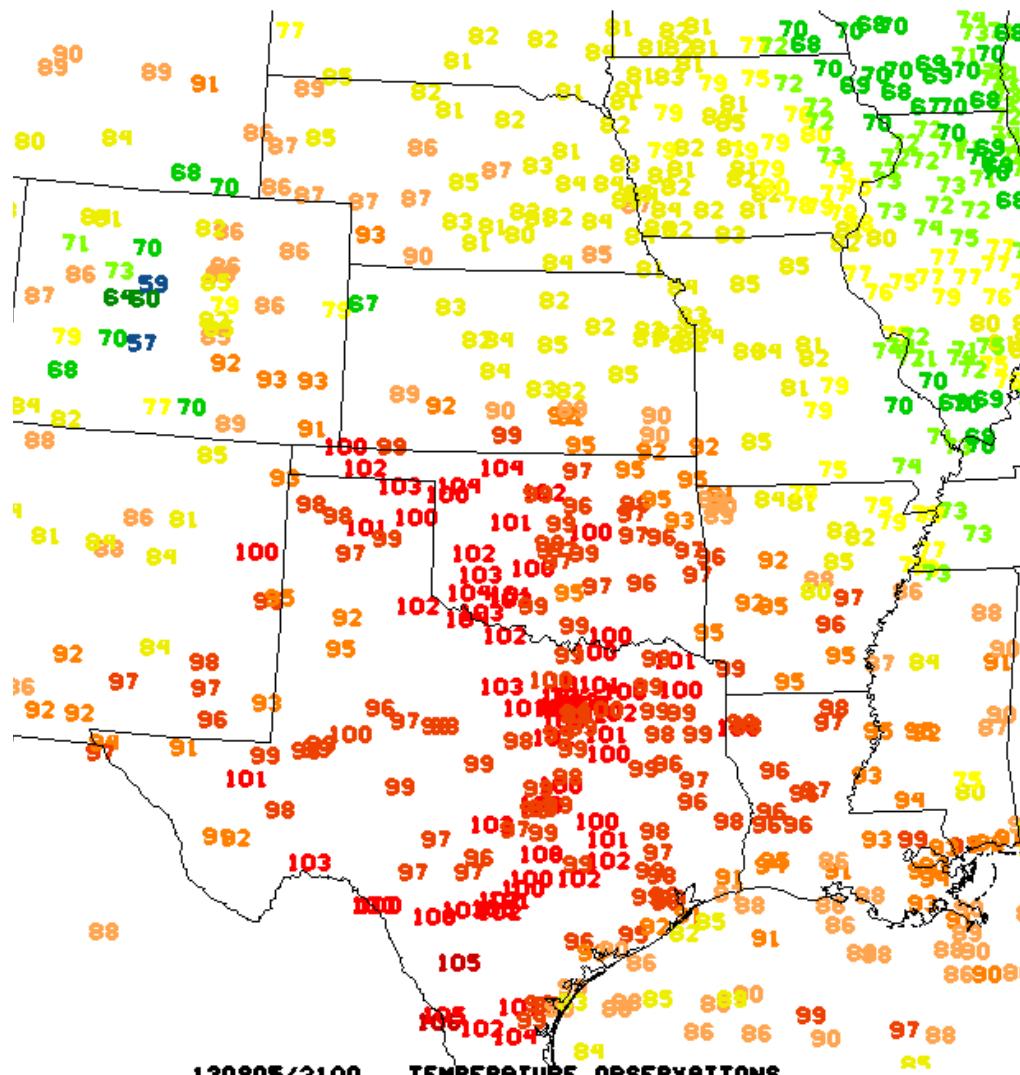
FCST MADE 12Z 08/05

RAPv2



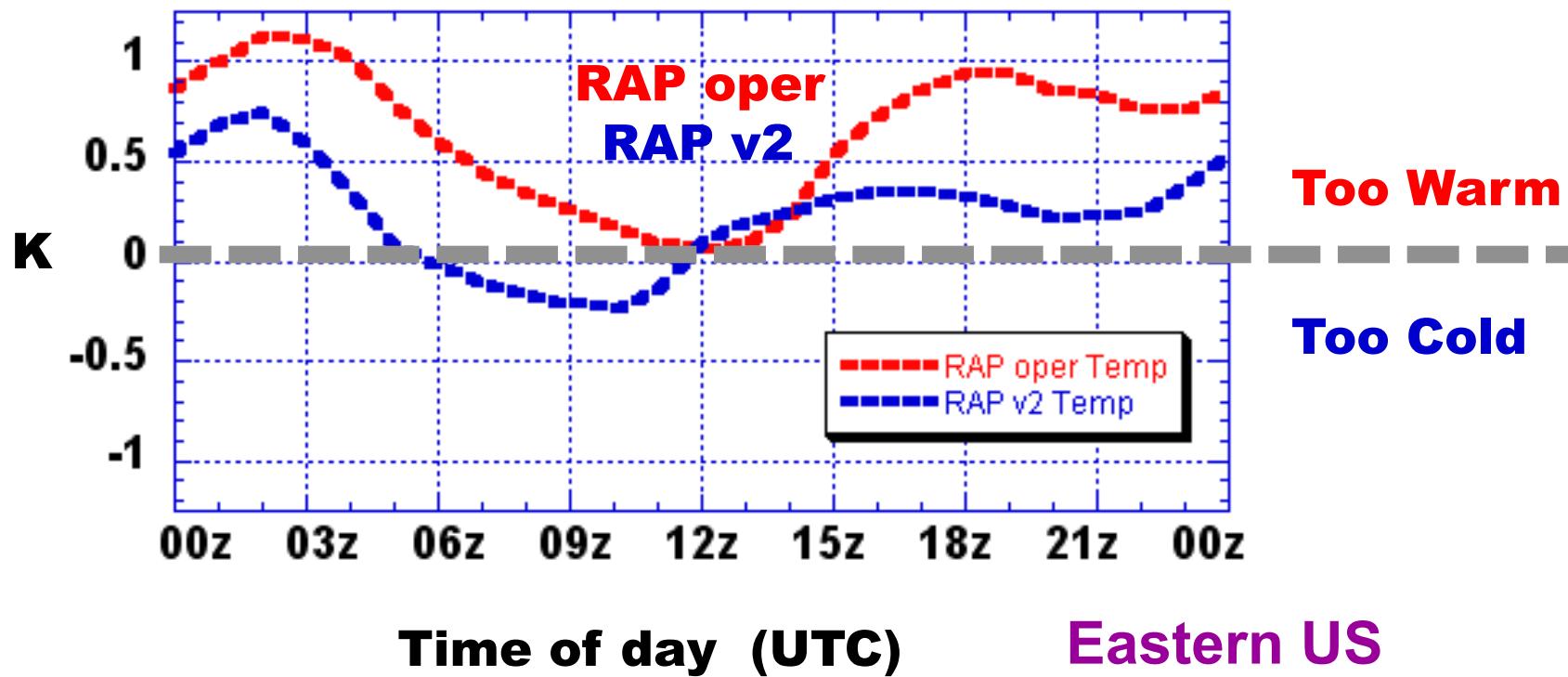
9h forecasts  
Valid 21z 5 August 2013

130805/2100 TEMPERATURE OBSERVATIONS



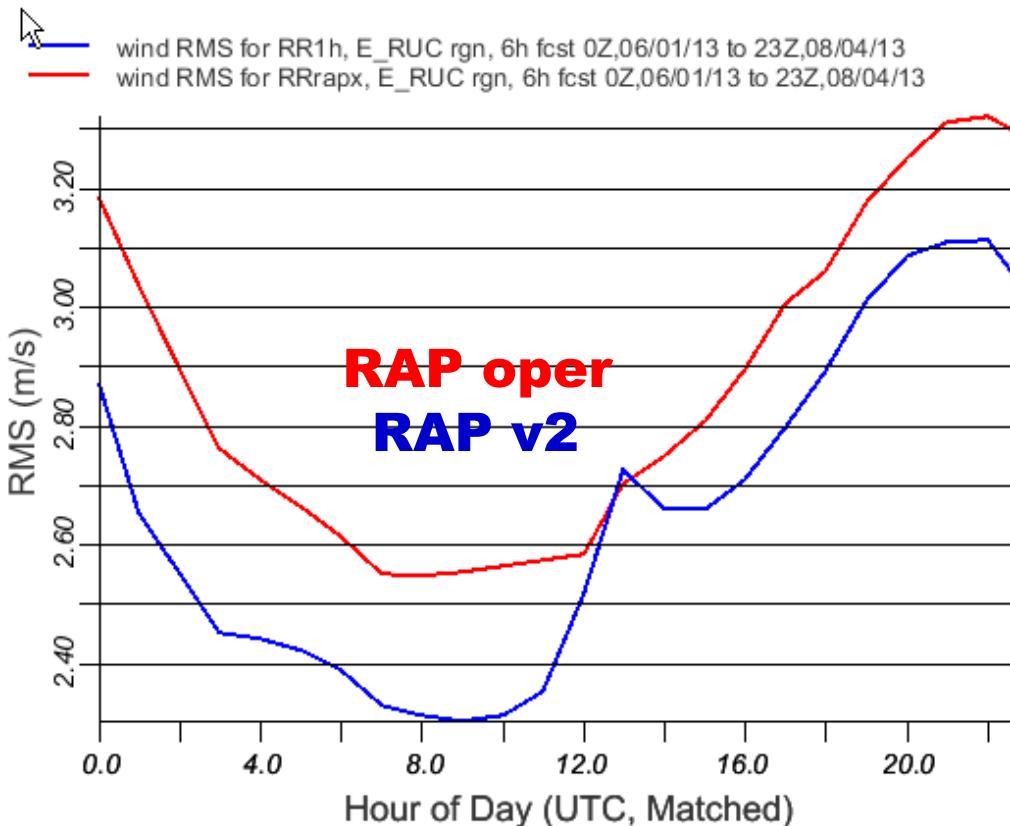


## 2m Temperature bias +3h fcst





# 10m Wind Speed RMS +6h fcst



**Time of day (UTC)**

**Eastern US**

**June 1 – August 5, 2013**



# HRRR Reflectivity Forecast Improvement



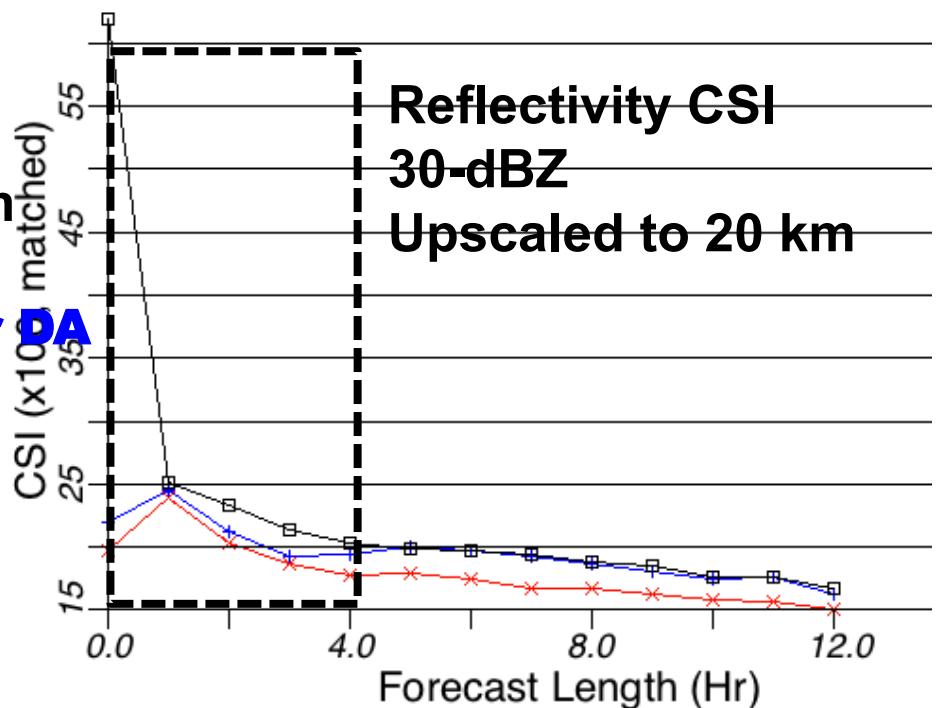
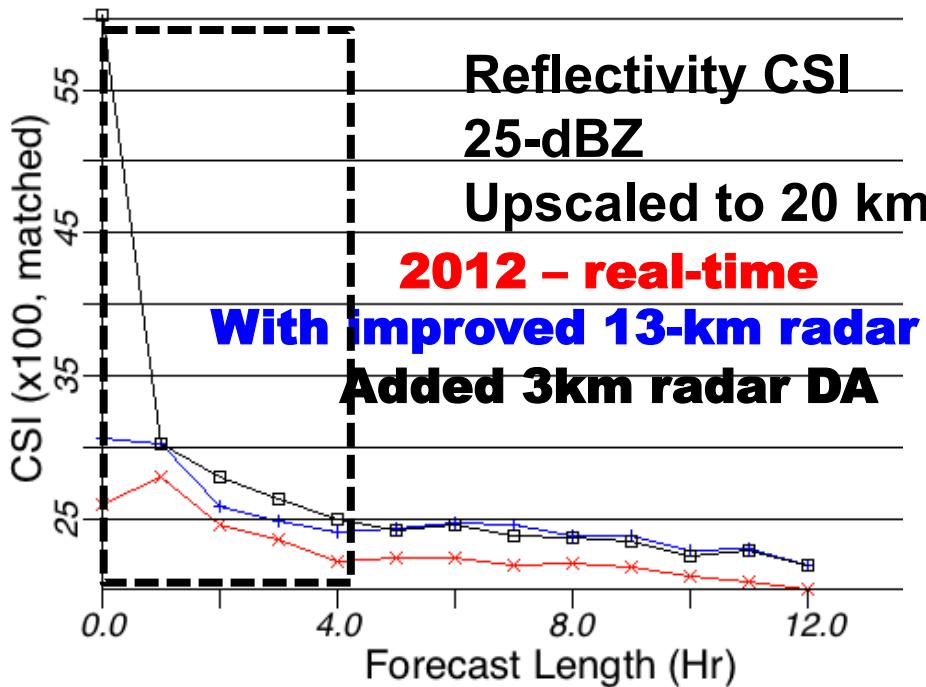
7-day retrospective period May-June 2012

Forecasts every 2 hours

> 25/30 dBZ Composite Reflectivity  
Eastern half of US

- CSI for HRRR\_June\_2012\_v7\_20km, EUS rgn, 25dBZ, All runs
- CSI for HRRR\_June\_2012\_v6\_20km, EUS rgn, 25dBZ, All runs
- CSI for HRRR\_20km, EUS rgn, 25dBZ, All runs 2012-05-29

- CSI for HRRR\_June\_2012\_v7\_20km, EUS rgn, 30dBZ, All runs
- CSI for HRRR\_June\_2012\_v6\_20km, EUS rgn, 30dBZ, All runs
- CSI for HRRR\_20km, EUS rgn, 30dBZ, All runs 2012-05-29

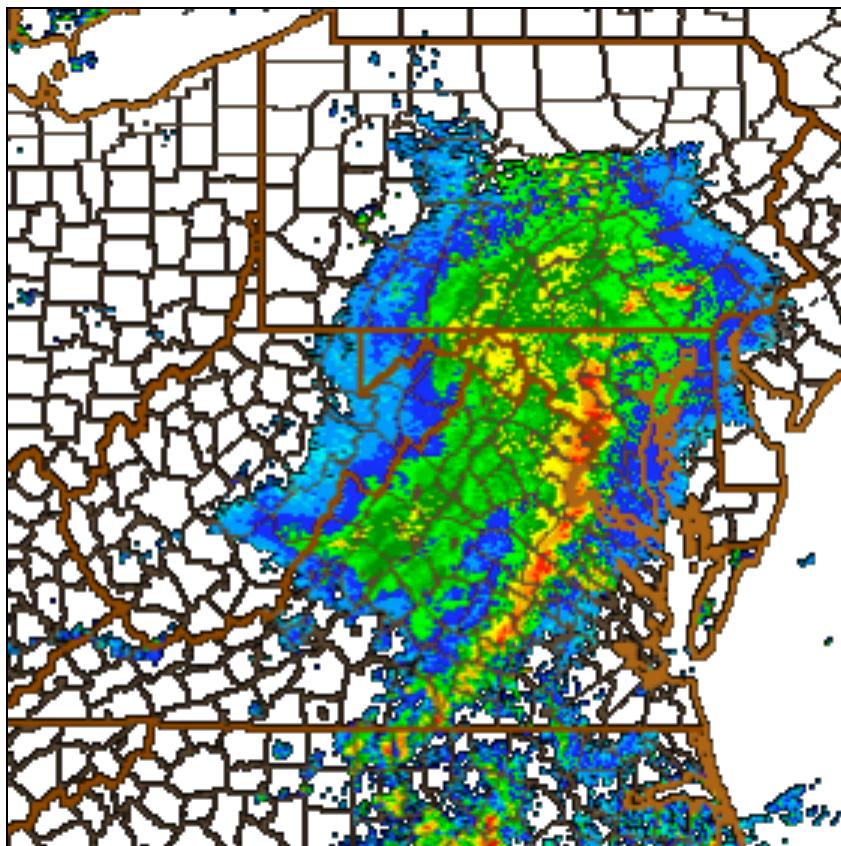


*Significant improvement in HRRR forecast skill each year,  
some from improved RAPv2 parent*

# NOAA Next-Generation RAP / HRRR System

## Forecast of Mid-Atlantic Derecho – 29 June 2012

**Radar observed**  
**Valid 11PM EDT**

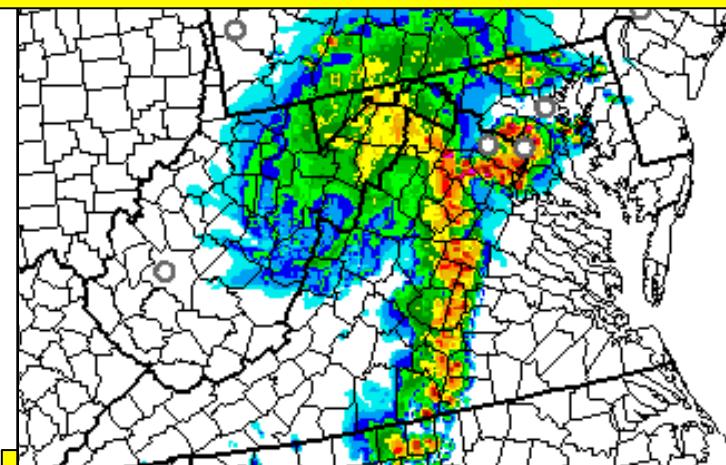


**Composite Reflectivity (dBZ)**

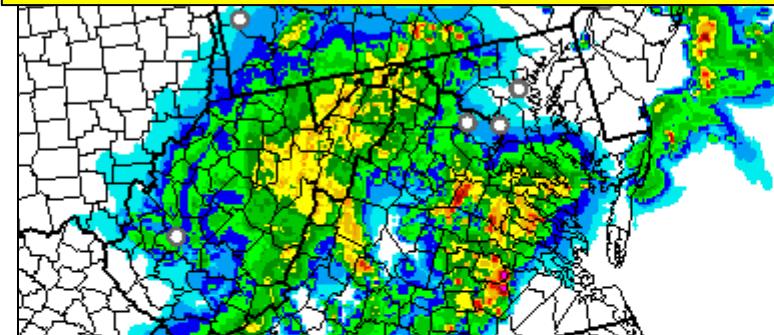


**HRRR 12-h forecast**

Real-time HRRR forecast init 15z



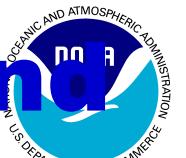
HRRR Experiment with 2011 RAPv1 DA



*Conclusion – improved RAP DA in 2012 critical for very good 29 June 12 real-time HRRR derecho forecast*

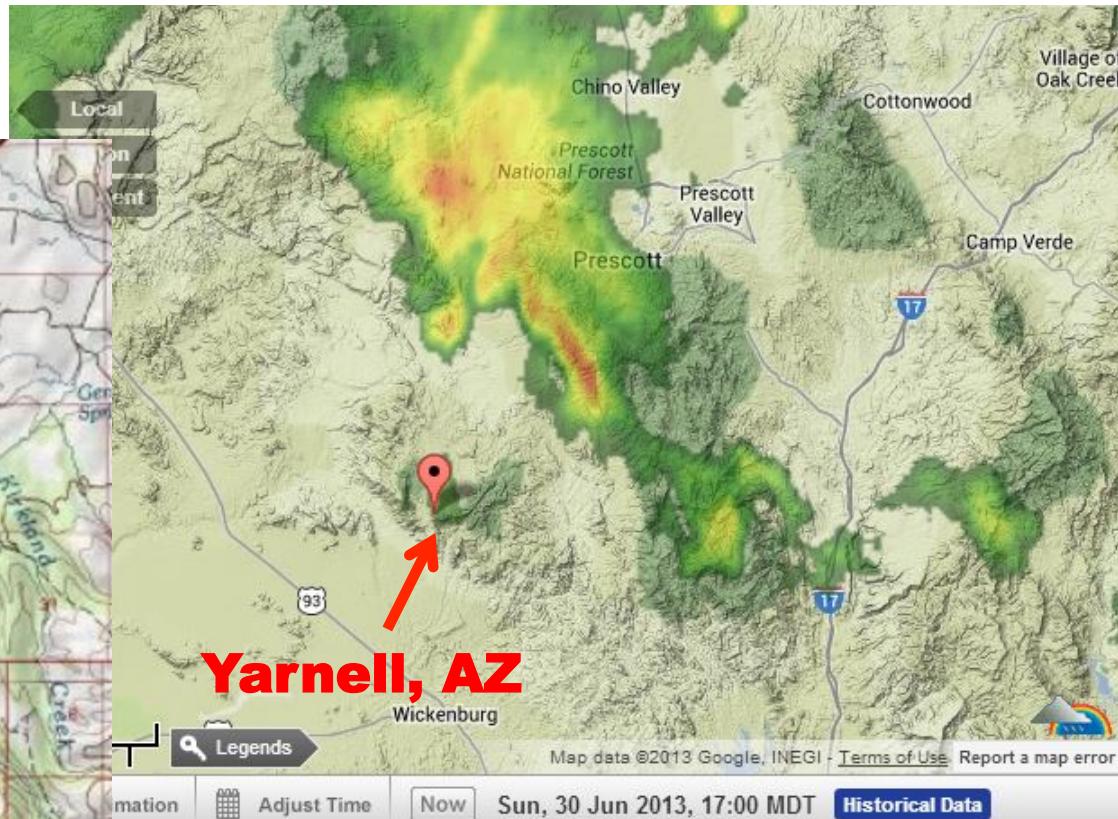
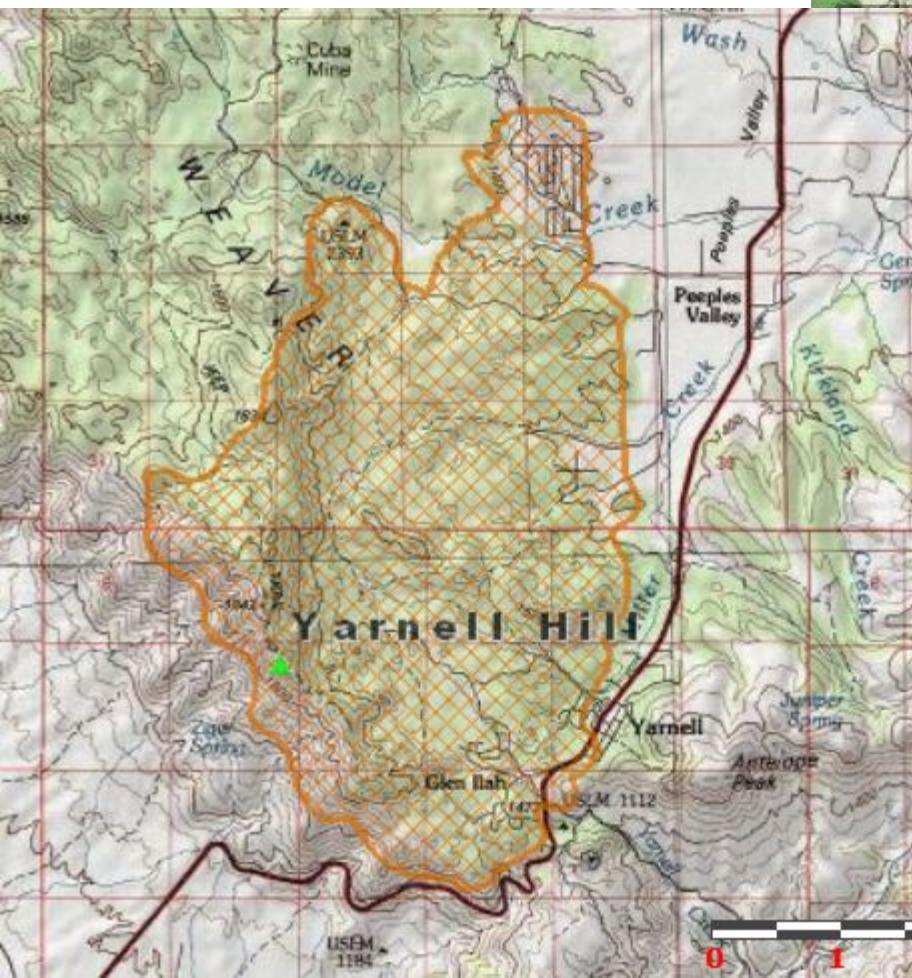


# Yarnell, AZ Wildfire Background

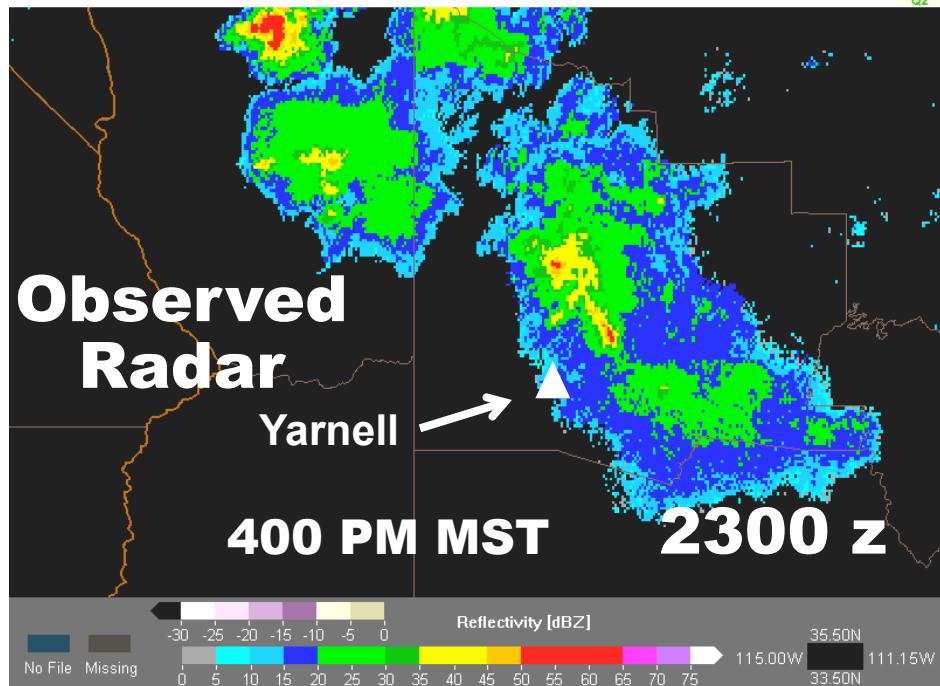
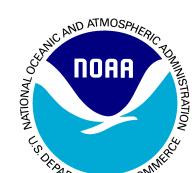


Radar Reflectivity  
4 PM MST June 30, 2013

July 2, 2013 Yarnell, AZ  
Wildfire Perimeter



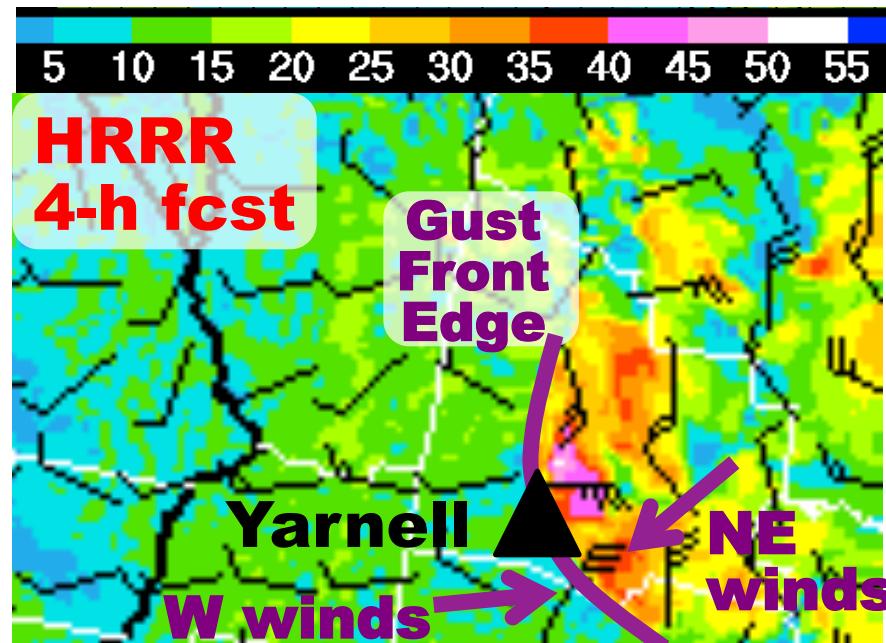
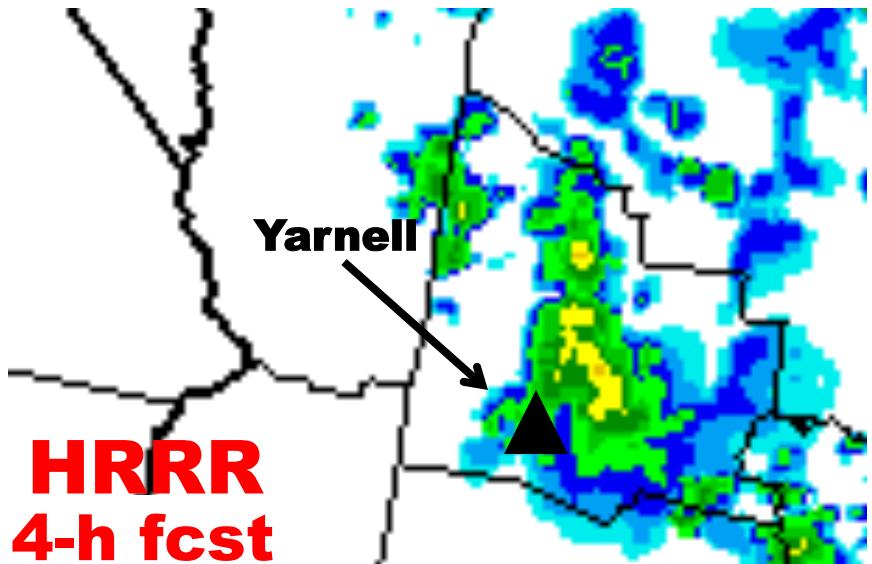
**Last contact with fire crew  
~ 4:30 PM MST  
(2330 UTC) Sun. 30 June, 2013**



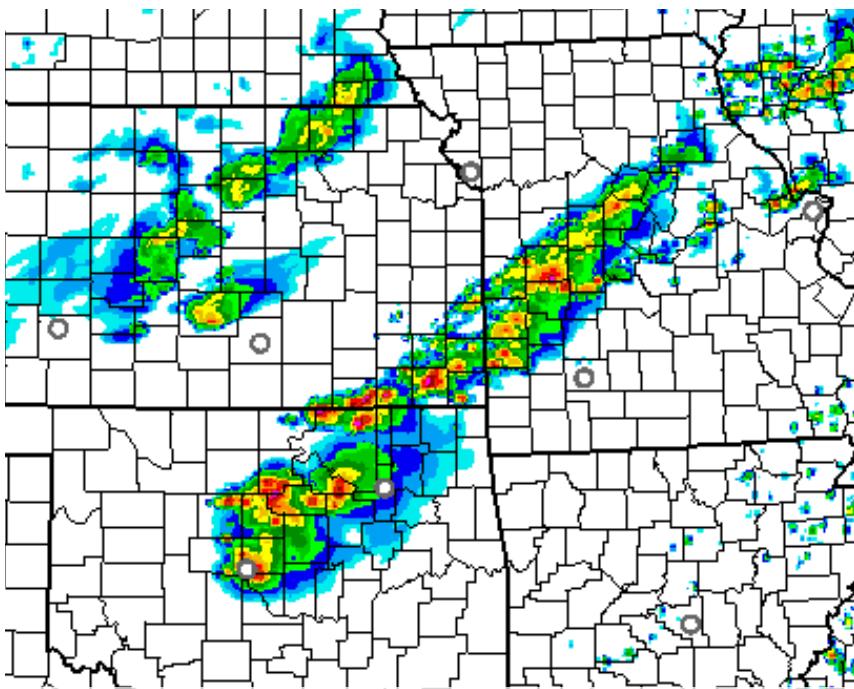
**HRRR forecast from  
1900 UTC (noon MST)  
model run, which is  
available by 2 PM MST**

**4-h HRRR forecast for 4 PM  
80 m AGL wind speed (kts)  
and wind direction (barbs)**

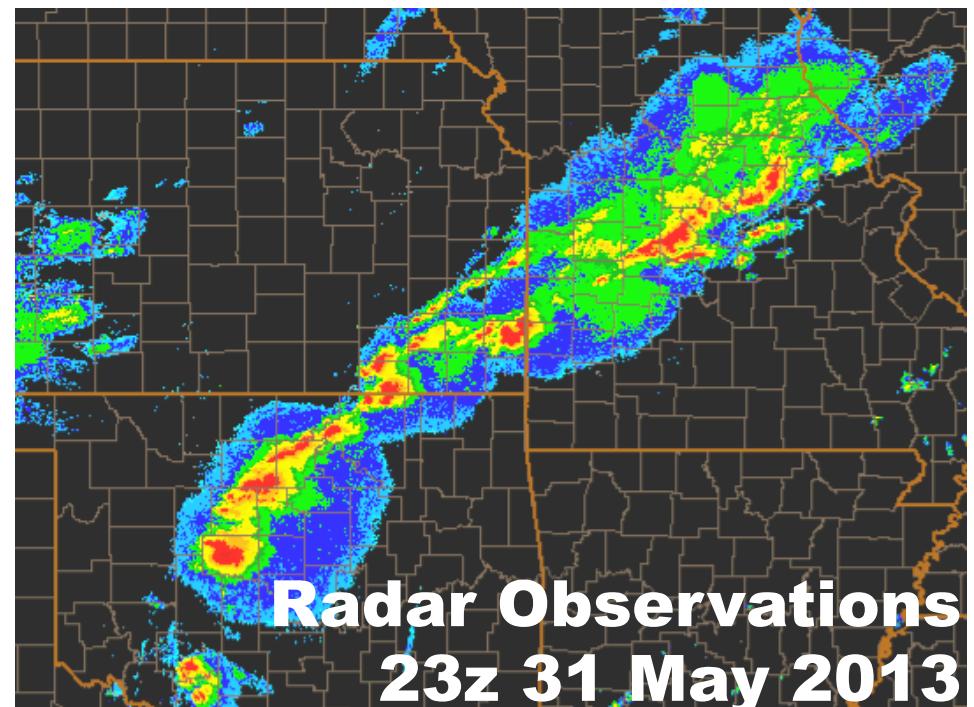
### HRRR forecast radar reflectivity



# 31 May 2013 Oklahoma/Missouri tornado/flashflood event



**HRRR 10-h forecast  
valid 23z 31 May**



**Radar Observations  
23z 31 May 2013**



# Verification of ESRL-RAP vs HRRR

Cold Season (01 Feb 2013 – 31 Mar 2013)

HRRR vs RAPv2

Lead Time	Clouds		Precip (13 km)		Reflectivity (40 km)		Upper-Air			Surface		
	Ceiling < 500 ft	Vis < 0.5 mile	> 0.1 inch	> 1.0 inch	25 dBZ	35 dBZ	Temp	RH	Wind	Temp	Dewpt	Wind
3-hr	HRRR	HRRR			HRRR	HRRR	Equal	Equal	RAP	Equal	Equal	Equal
6-hr	HRRR	HRRR	Equal	Equal	HRRR	HRRR	Equal	Equal	RAP	Equal	HRRR	Equal
12-hr	HRRR	HRRR	Equal	HRRR	HRRR	HRRR	Equal	Equal	RAP	Equal	HRRR	Equal

Warm Season (01 May 2013 – 25 June 2013)

HRRR vs RAP

Lead Time	Clouds		Precip (13 km)		Reflectivity (40 km)		Upper-Air			Surface		
	Ceiling < 500 ft	Vis < 0.5 mile	> 0.1 inch	> 1.0 inch	25 dBZ	35 dBZ	Temp	RH	Wind	Temp	Dewpt	Wind
3-hr	HRRR	HRRR			HRRR	HRRR	RAP	RAP	RAP	Equal	Equal	RAP
6-hr	HRRR	HRRR	Equal	HRRR	HRRR	HRRR	Equal	Equal	RAP	Equal	Equal	RAP
12-hr	Equal	Equal	HRRR	HRRR	HRRR	HRRR	HRRR	HRRR	RAP	HRRR	HRRR	RAP



# Pre-Implementation RAPv2 Test Results



- RAPV2 Statistics available from ESRL runs
- Clear improvement in ESRL parallel RAPv2 for
  - Upper-level wind, RH, temperature
  - 2m temp, 2m dewpoint, 10m wind
  - Evolution of soil moisture (dependent on 1h precipitation and, especially, radar reflectivity assimilation)
- Evidence of 2-m temperature improvement also in EMC parallel RAPv2
- General synoptic improvement in ESRL parallel
- Examples from ESRL of improvement related to radiation fix and snow cover improvement

# 13km Rapid Refresh and 3km HRRR hourly updated weather models

## ESRL – experimental version

- RAPv1 – used in 2011
  - Initialized 2011 HRRR
  - Effective but too many storms
- RAPv2 – used in 2012
  - Initialized 2012 HRRR
  - Better use of surface obs / radar, storm bias eliminated
  - **RAP-2013 – improved radar assim, GOES cloud assim, ensemble assim**
- HRRR – 2012
  - Major improvement over 2011 HRRR, storm coverage/accuracy
- **HRRR – 2013**
  - **3km/15min radar assimilation**
  - Initialized from RAP-2013
  - Available 45 min earlier, much more accurate 0-15h storm forecasts

## NWS-NCEP - operational

- Implemented 1 May 2012
- RAPv2 - Scheduled to be implemented - Dec 2013
- HRRR – estimated early 2014